Improvements in Bandwidth & Wavelength Control for XLR 660xi Systems

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ABSTRACT

As chipmakers continue to reduce feature sizes and shrink CDs on the wafer to meet customer needs, Cymer continues developing light sources that enable advanced lithography, and introducing innovations to improve productivity, wafer yield, and cost of ownership. In particular, the architecture provides dose control and improved spectral bandwidth stability, both of which enables superior CD control and wafer yield for the chipmaker.

The XLR 660ix incorporates new controller technology called ETC for improvements in spectral bandwidth stability, energy dose stability, and wavelength stability. This translates to improved CD control and higher wafer yields. The authors will discuss the impact that these improvements will have in advanced lithography applications.

1. INTRODUCTION

Double-patterning ArF immersion lithography continues to advance the patterning resolution and overlay requirements and has enabled the continuation of semiconductor bit scaling. Over the years, Lithography Engineers continue to focus on CD control, overlay and process capability to meet current node requirements for yield and device performance. Reducing or eliminating variability in any process will have significant impact, but the sources of variability in any lithography process are many. The goal from the light source manufacturer is to further enable capability and reduce variation through a number of parameters. Table 1 summarizes the lithography parameter and the light source requirement. [1, 2, 3, 4]

Table 1

Litho parameters	Light source requirements
Contrast, CD Control	Bandwidth control & stability
Dose Control	Energy control & stability
Focus, Overlay	Wavelength control & stability

2. WHAT IS ETC?

ETC is a collection of new algorithms for XLR660ix light sources that execute in real time to tightly control the system's energy and dose, central wavelength, and spectral bandwidth. These algorithms comprise linear and nonlinear elements, adaptive feedback and feed-forward, multivariable architectures, and specialized knowledge bases earned through Cymer's years of light source research and development. Under tightening requirements for next generation scanners, the new algorithms instantiate advanced actuation techniques to improve speed and accuracy. However, these techniques also increase the complex coupling between the various light source subsystems. Additionally, the effects of exogenous disturbances – previously rejected through straightforward feedback – became a significant fraction of the requirements budget. Therefore, the algorithms also needed to decouple disparate parameter interactions, and simultaneously precisely characterize and fully reject the largest disturbances. The result is a tightly interacting high performance controller able to achieve the necessary improvements without any changes to XLR660ix hardware.

More academically, the design of ETC deeply understands the light source's dynamics and disturbances. It uses this to push its model-based feedback designs to the edge of robust stability limits. It also incorporates advanced adaptive and learning techniques to further push performance bounds while maintaining stability. For example, the effects of firing duty cycle on performance parameters are known to vary over time and between systems; the ETC algorithms adapt models of these effects to the current time and system and apply the model to improve control. ETC is therefore more than a set of algorithms; it is the application of the accumulation of systems knowledge coupled to advanced methods to deliver the tight control in energy, wavelength, and bandwidth that the next generation scanners need.

3. IMPROVED STABILITY CONTROL

Figure 1 is a diagram of the XLR 660ix system highlighting the location of the line-narrowing module (LNM), the master oscillator (MO) and power ring amplifier (PRA), the pulse power modules and new software to enable algorithms in the light source. There are no changes in the current hardware design of the light source to enable these improvements.

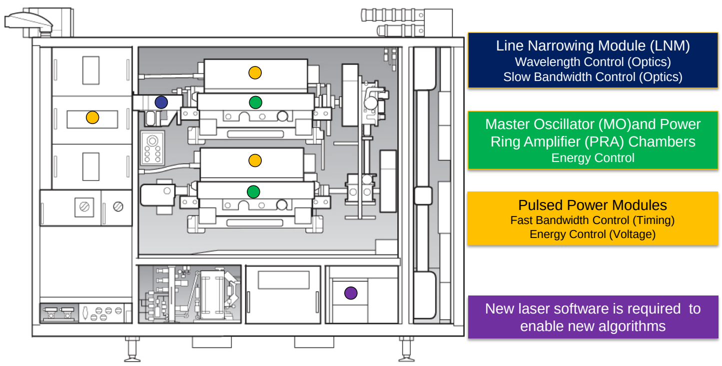
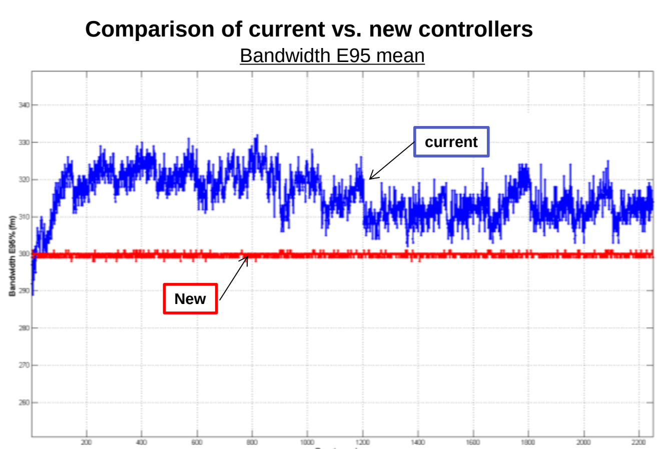


Figure 1

4. RESULTS & DISCUSSION

4.1 Bandwidth stability

To achieve ever-increasing demands of contrast and CD control, stability of spectral bandwidth is essential. With introduction of ETC we now control the spectral bandwidth pulse by pulse. This enables us to maintain the bandwidth mean to within ±3fm of the target as shown in Figure 2. Also shown is legacy bandwidth performance, which clearly illustrates the leap in performance brought by ETC.



Simulated wafer exposure pattern demonstrates the advantage of fast bandwidth control

Figure 2 – Enhanced bandwidth stability enables improved CD uniformity

As inherent bandwidth disturbances of light source are hardware dependent, they differ in magnitude and severity from system to system. This is the reason that ETC's adaptability and learning ability, discussed in Section 2, play a key role in maintaining the same level of performance on different systems. In Figure 3 we show bandwidth mean (top plot) and die minimum/maximum values (bottom plot) for nine ETC systems currently in the field. Data is taken using simulated wafer-exposure firing pattern, and it includes 2250 dies. It is clear that mean bandwidth is kept within ±3fm of the target, with extreme values in die reaching ±12 fm. This clearly shows robustness and repeatability of ETC bandwidth control.

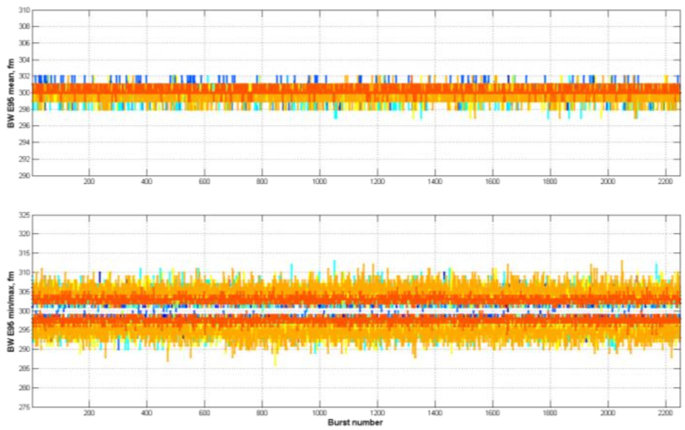


Figure 3 – Bandwidth control over 9 systems currently in the field

4.2 Wavelength stability

Scanner stage speeds continue to increase to support the higher throughput demands of chipmakers. Scanner focus and overlay requirements are tightening. To the light source, a higher stage speed corresponds to fewer pulses which can be used for control purposes as the imaging slit passes across the exposure field, and tighter focus and overlay requirements imply the light source wavelength stability needs to be tighter Cymer has introduced a new wavelength controller with the ETC which improves wavelength stability performance even with >25% reduction in the number of pulses averaged by the slit. This controller continually predicts the inherent light source disturbances and the physical state of the wavelength actuators, and uses optimal feedback control methodology to provide the highest level of wavelength control performance Cymer has ever achieved. A comparison of our previous controller and the ETC wavelength controller performance is provided in Figure 5. Both of the wavelength metrics (average error and moving sigma) commonly used to characterize wavelength stability of a DUV light source show significant improvement. Enhanced wavelength stability enables improved CD uniformity with slit reduced by 25%.

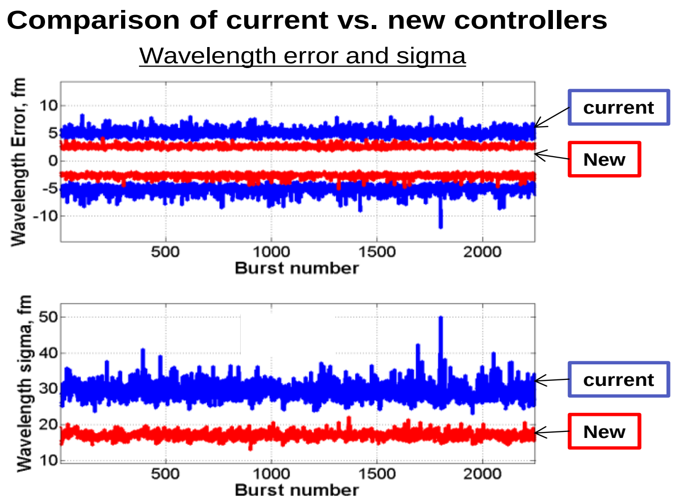


Figure 4

4.3 Dose stability performance

Similarly, to wavelength, the increased stage speeds also are demanding on the dose control that the light source provides. The dose controller also is coupled into other ETC controllers for bandwidth. These two factors required advanced solutions for dose control to maintain the high level of performance expected by chipmakers, which the Cymer light source is able to provide with the introduction of ETC. Slit size reduce by 25% with no performance penalty. BW & WL stability requirements were achieved with no impact to dose stability

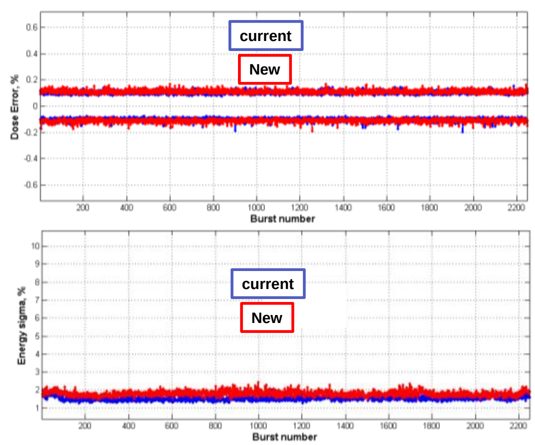


Figure 5

5 CONCLUSIONS

In this paper, the Authors have demonstrated a new controller technology for improvements in spectral bandwidth stability, energy dose stability, and wavelength stability. We have demonstrated performance over multiple systems, which have been deployed at multiple chipmakers. This performance will translate into improved CD control and higher wafer yields. ETC offers substantial improvement in both wavelength & bandwidth control, as well as improvements to energy control to allow operation with the slit reduced by up to 25%. ETC algorithms have been deployed next generation scanners and have demonstrated real improvements, which can be made by algorithm only changes rather than hardware development.

6 REFERENCES

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